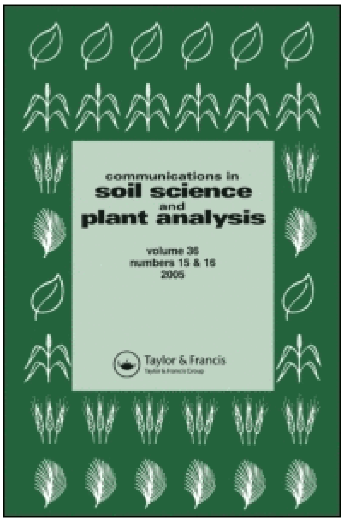

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Effects of Source and Amount of Phosphorus on Sorption Kinetics in the Topsoil of a Highly Weathered Soil

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Effects of Source and Amount of Phosphorus on Sorption Kinetics in the Topsoil of a Highly Weathered Soil

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Abstract: Soil chemical and physical reactions involving phosphorus (P) must be understood to predict the risk of P being transported from agricultural land to streams and lakes. The kinetics of P sorption by an Ultisols from West Virginia, USA, receiving P from fertilizers were compared to soils amended with turkey litter. Addition of 6.6 and 13.2 Mg turkey litter ha^{-1} increased Bray 1P levels to about the same level as adding 53 and 115 kg P ha^{-1}, respectively. Phosphorus binding capacity decreased to a greater extent when P was added as fertilizer as compared to turkey litter. For example, P binding maximum was 360 mg P kg^{-1} dry soil when soil was amended with 6.6 Mg turkey litter ha^{-1} as compared to 260 mg P kg^{-1} dry soil when amended with 53 kg P ha^{-1}. This study demonstrates that the decrease in P-binding capacity with increasing soil P is less when P is added as turkey litter.

Keywords: Binding capacity, binding constant, fertilizer, mineralization, phosphorus, sorption, turkey litter

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INTRODUCTION

Many farms in the southeast United States are integrated operations with poultry and cattle production components. Typically, poultry operations, import large amounts of nutrients as animal feed. A majority of these nutrients are retained on farm as animal waste, which is used to supply nitrogen (N) and phosphorus (P) to forages to produce beef. Essentially, the forage–cattle operation is a means to utilize waste from the poultry operation in an economically beneficial manner.

Sustained application of poultry litter to satisfy the N needs of forages can lead to excessive accumulation of P in soils, because P is more abundant than N in litter relative to plant needs (Correll 1998). In Arkansas, Mehlich III soil tests in 1999 showed that more than 60% of soil samples from counties with high-intensity poultry production had high soil test values for P (STP) and more than 30% were very high (DeLong et al. 2000). One concern regarding high STP is the potential for P transport from agricultural fields to surface water, leading to degraded water quality (Correll 1998).

Soil chemical and physical reactions involving P must be thoroughly understood so that the risk associated with P transport from agricultural lands to surface waters can be predicted. Chemical reactions of P with other mineral elements and reactive surface in soil are complex and numerous. In general, addition of P to soils decreases the capacity of soil to bind P (Beauchemin, Simard, and Cluis 1996; Indiati 2000; Indiati et al. 1995; Mullins 1991; Raven and Hossmer 1994; Whalen and Chang 2002). The addition of organic constituents to soil also affects chemical and binding reactions of soil P. Mechanisms include: 1) solubilization of P by organic acids; 2) complexation between organic acids and Al and Fe, thus reducing P complexation; 3) competition of organic anions for sites that bind phosphate; and 4) changes in surface charges. Effects of added organic additions on the binding characteristics are dependent on the type of organic matter (Singh and Jones 1976) and the soil type (Iyamuremye and Dick 1996). Whalen and Chang (2002) investigated P-sorption capabilities of soils amended with long-term applications of varying amounts of animal manures and observed decreased P-sorption capacity with increasing manure applications. However, the decrease was less than 50% that of the maximum binding capacity of unamended soils. Whalen and Chang (2002) postulated that the less-than-expected decline in sorption capacity occurred from changes in soil organic matter content, pH, and other surface chemistry properties. Therefore, increasing soil P by addition of manures may affect P-sorption capacity of soil differently than if P is added as an inorganic fertilizer. This study compares P-sorption capacities of a highly weathered soil (Ultisols) when P is added as either turkey litter or fertilizer.

MATERIALS AND METHODS

Characterization of Experimental Site

The field experiment was located near New, WV, USA (N 37.67, W 80.60) and conducted on Gilpin silt loam (fine-loamy, mixed, semi-active, mesic, Typic Hapludult). The Gilpin series soil is moderately deep and well drained, forming on the rolling shale and sandstone ridges and mountainsides of the Allegheny plateau. Natural fertility is moderate. The surface horizon (A_p) tends to be about 20 cm deep with granular structure. A bulk soil sample was collected from the A_p horizon (0–15 cm) in March 1996 just prior to establishing pastures.

A sward of orchardgrass (*Dactylis glomerata* L., cv. Benchmark), white clover (*Trifolium repens* L., cv. Grasslands Huia), and chicory (*Cichorium intybus* L., cv. Grasslands Puna) was established on a prepared seedbed in 1996. Limestone was applied at 4.4 Mg ha^{-1} based on soil-test recommendations, and a starter application of fertilizer of 220 kg of 10–20–20 ha^{-1} was applied at seeding. The area was divided with electrical fencing into eight strips containing 0.2 ha with strips accommodating two replicates of four treatments. Treatments were 6.6 and 13.2 Mg composted turkey litter ha^{-1}; N–P–potassium (K); or P–K fertilizer applied in early April 1996 and then every 2 years thereafter. Additional details regarding establishment and agronomic practices are presented in Belesky et al. (1999) and Turner, Belesky, and Fedders (1999).

Samples of the turkey litter were analyzed for percentage of moisture, and N, P, and K concentrations by the West Virginia Department of Agriculture (Charleston, WV). The N–P–K and P–K fertilizer was applied so that P supplied was the same as that supplied by 6.6 Mg of turkey litter ha^{-1} (i.e., 53 kg P ha^{-1}). One-kilogram aliquots of turkey litter were stored frozen at $-20°C$ in triple-bagged containers for use in laboratory incubation studies. Plots were grazed by lambs throughout the spring, summer, and early fall. Soil samples (0–15 cm) were collected in September 1997 after two grazing seasons and prior to the second application of turkey litter. Data regarding forage and animal performance were reported earlier (Belesky et al. 1999).

Laboratory Incubation Experiments

Soil from the bulk collection made in March 1996 was air dried, ground to pass a 2-mm sieve, and stored in plastic container under ambient conditions until used. Immediately prior to initiation of incubation experiments, soil was separated into 250-g (air dry weight) aliquots. Triple superphosphate (0–46–0) or turkey litter was added and mixed thoroughly. Distilled water (75 g of H_2O per 250 g of soil) was added in several portions as a fine mist, mixing thoroughly in between additions. Soil was placed inside of two resealable plastic bags. Bags were placed in a box in a random order and stored at 20–25°C. The mass of the bags plus soil was checked weekly, and bags were rerandomized. Distilled water was added to samples when the mass of the bagged samples had declined by more than 2% of the original mass. Bags were incubated for up to 16 weeks. Each bag represented an experimental unit of one incubation time for each treatment within one replication. Each experiment contained four replications, and each experiment was repeated twice. Additions of turkey litter and triple superphosphate were converted to a land-area basis by assuming 2 Mg of soil (dry weight) ha^{-1} so that results could be readily compared to the field experiment.

Two 20-g aliquots of wet soil were removed from each bag and extracted with 50 ml of 2 M KCl for nitrate determinations. Two additional 20-g aliquots of soil were air dried to determine moisture content. The remainder of the soil was air-dried and ground to pass a 0.2-mm sieve for soil P analyses.

Soil Analyses

Soil nitrate concentrations in 2 M potassium chloride (KCl) extracts were determined colorimetrically after reduction and reacting the resulting nitrite with sulphanilamide and N-(1napthyl)-ethylenediamine dihydrochloride. Bray 1 P levels were determined as described previously (Olsen and Sommers 1982). Total soil P was determined by the digestion method (Olsen and Sommers 1982) used by the West Virginia Department of Agriculture (Charleston, WV). Total inorganic soil P was determined after sequential extractions of a soil sample with hydrochloric acid (HCl), sodium hyrdroxide (NaOH), and hot NaOH (Mozaffari and Sims 1996). Organic P was determined by subtracting total inorganic soil P from the total soil P. All soil-test values are expressed on a dry-soil basis. Phosphorus sorption isotherms were constructed in the presence of KCl (Graetz and Nair 2000). Data were fit to the Freundlich equation by plotting the reciprocals of P binding as a function of the reciprocals of P solution concentrations. In such plots, the Y-intercept is equal to the reciprocal of the maximum capacity of P binding, and the slope is equal to the binding affinity constant (Kf) divided by maximum binding.

Statistical Analyses

Data from the field experiment were averaged across replications, whereas data from laboratory incubation experiments were averaged across replications within an experiment and replicate experiments. These means were used in regression analyses. Regression equations among independent variables and between independent and dependent treatment variables were calculated using ProcReg (SAS 1999). Standard errors of the means are presented as a measure of variation.

RESULTS AND DISCUSSION

The appearance of nitrate over time was followed as an indicator of the rate of decomposition of the turkey litter added to the Gilpin series soil during the laboratory incubation experiment (Figure 1). Soil nitrate levels reached maximum values in unamended and turkey litter–amended soils after 8 weeks of incubation. These results suggest that most turkey litter decomposition occurred during the first 8 weeks of incubation.

Unamended soil had about 75% of total soil P in the inorganic pool (Figure 2). The percentage of total soil P as inorganic increased to almost 80% in soils amended with 6.6 Mg turkey litter ha^{-1} due to high abundance of inorganic P in the turkey litter (Figure 2). The fraction of the total P in the inorganic pool decreased to be about the same as unamended soils after at least 10 weeks of incubation. Therefore, an incubation period of 12 weeks was set for studies on the effects of P source on P-sorption isotherms, based on changes in partitioning soil P between organic and inorganic pools and nitrate production.

Incubation of soil had little effect on Bray 1 P values (Table 1). Bray 1 P values averaged about 62 mg P kg^{-1} soil for samples analyzed from the bulk sample and after aliquots of the bulk sample were rehydrated and incubated up to 12 weeks. The addition of increasing increments of either turkey litter resulted in progressive increases in Bray 1 P values. The resulting Bray 1 P values were essentially the same for samples from the laboratory and field experiments. The addition of 53 kg P ha^{-1} as fertilizer increased Bray 1 P values similarly for samples from both the field and laboratory experiments,

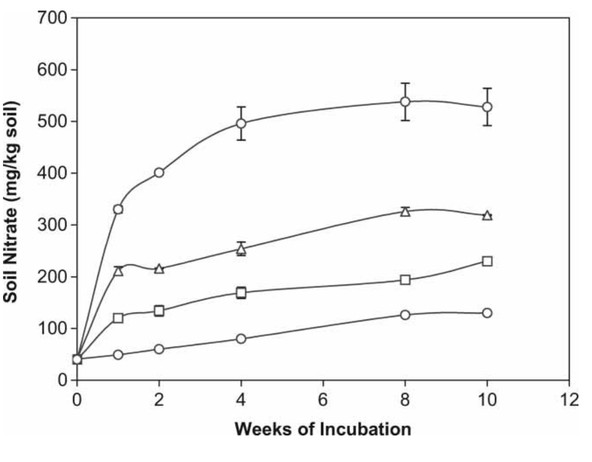

Figure 1. Effects of incubation period and addition of turkey litter on the levels of soil nitrate. Soils were incubated in the laboratory for 0 to 10 weeks with the equivalent of 0 (○), 6.6 (□), 13.2 (Δ), or 26.4 (○) mg turkey litter ha^{-1} and then extracted and analyzed for nitrate nitrogen.

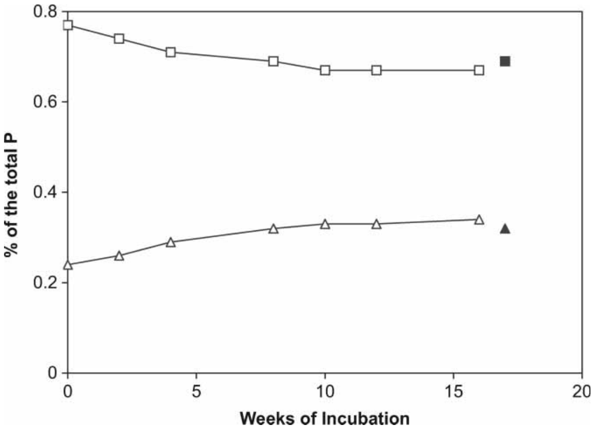

Figure 2. Effects of incubation on the distribution of soil P between inorganic and organic pools after the addition of turkey litter. Soils amended with 26.4 Mg of turkey litter ha^{-1}, and incubated in the laboratory for 0 to 16 weeks prior to analyses to determine inorganic (□) and organic (Δ) soil P levels. Open and closed symbols represent data from turkey litter amended and unamended soil, respectively.

and these values were similar to those found after the addition of 6.6 Mg turkey litter ha^{-1}. The addition of 13.2 and 26.4 Mg turkey litter ha^{-1} resulted in Bray 1 P values similar to those obtained by the addition of 115 and 233 kg P ha^{-1} as triple superphosphate in the laboratory experiment.

Table 1. Effects of poultry litter and fertilizer additions on the Bray 1 P soil-test values

Experiment	Soil fertility treatment	Bray1 P soil-test values (mg P kg^{-1} soil)
	Prior to treatments	61.8 ± 4.2[a]
Laboratory	unamended	62.3 ± 4.0
Laboratory	6.6 Mg litter ha^{-1}	77.1 ± 2.0
Field	6.6 Mg litter ha^{-1}	77.1 ± 2.0
Laboratory	13.2 Mg litter ha^{-1}	88.5 ± 1.4
Field	13.2 Mg litter ha^{-1}	87.5 ± 1.6
Laboratory	26.4 Mg litter ha^{-1}	98.4 ± 2.0
Laboratory	53 kg P ha^{-1}	77.4 ± 3.8
Field	53 kg P ha^{-1} as K, P	77.4 ± 3.8
Field	53 kg P ha^{-1} as N, K, P	78.2 ± 1.8
Laboratory	115 kg P ha^{-1}	88.2 ± 1.8
Laboratory	233 kg P ha^{-1}	93.9 ± 2.0

[a]Mean + standard error of the mean.

The regression equations between soil additions and resulting Bray 1 P values were: 1) for turkey litter applications, Bray 1 P values (mg P kg^{-1} soil) = 67.2 + 1.33 (Mg ha^{-1}), F-value for model = 45.1, P > 0.003; and 2) for fertilizer additions, Bray 1P values (mg P kg^{-1} soil) = 70.5 + 0.136 (kg P ha^{-1}), F-value for model = 12.85, P > 0.023.

Binding capacity declined with increasing Bray 1 P values (Figure 3), but the data from soils receiving fertilizer and turkey litter segregated into two different trend lines, independent of whether the data were from field or laboratory experiments. Relationships between Bray 1 P and binding capacity were described by quadratic equations: 1) for soils receiving turkey litter, binding capacity (mg P kg^{-1} soil) = 1865 − 31.1 (mg Bray 1 P kg^{-1} soil) + 0.16 (mg Bray 1 P kg^{-1} soil)^2, F-value for model 237.6, P > 0.001; and 2) for soils receiving fertilizer, binding capacity (mg P kg^{-1} soil) = 3658 − 77.9 (mg Bray 1 P kg^{-1} soil) + 0.44 (mg Bray 1 P kg^{-1} soil)^2, F-value for model = 145.3, P > 0.001.

There was little change in Kf for P sorption with increasing Bray 1 P values when P was added as fertilizer (Figure 4). The regression equation using data from soils receiving fertilizer was Kf (μM) = 31.7 − 0.008 (mg Bray 1 P kg^{-1} soil), F-value for model = 0.04, P > 0.85; the regression model was not statistically significant. Value for Kf increased with increasing Bray 1 P values when soils were amended with turkey litter: Kf (μM) = 10.2 + 0.32 (mg Bray 1 P kg^{-1} soil), F-value for model = 68.4, P > 0.001.

As observed previously (Beauchemin, Simard, and cluis, 1996; Indiati 2000; Indiati et al. 1995; Mullins 1991; Raven and Hossmer 1994; Whalen and Chang 2002), the addition of P to soils decreased the soil's

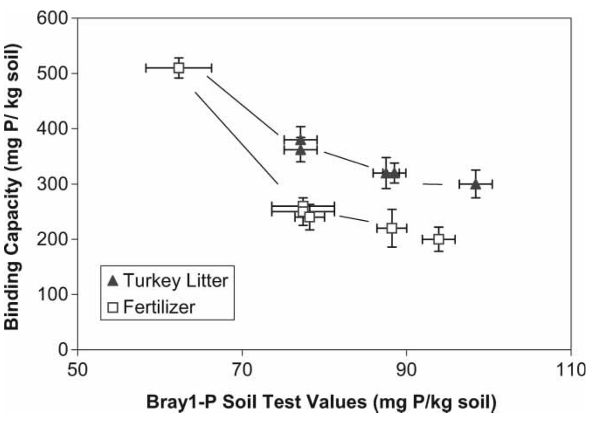

Figure 3. Effects of source of P on the relationship between P binding capacity and Bray 1 P soil-test values. Data from soils receiving fertilizer (□) and turkey litter (▲) are means from both the field and laboratory experiments. Bars represent standard error of the means for both binding capacity and Bray 1 P values.

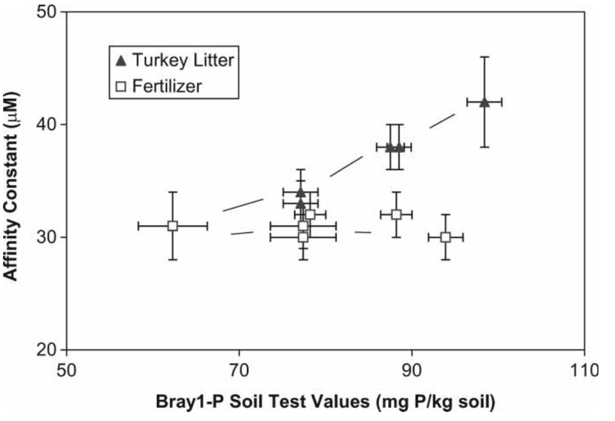

Figure 4. Effects of source of P on the relationship between affinity constant, Kf, and Bray 1 P soil-test values. Data from soils receiving fertilizer (□) and turkey litter (▲) are means from both the field and laboratory experiments. Bars represent standard error of the means for both binding capacity and Bray 1 P values.

capacity to bind P-(Figure 3). This study demonstrates by direct comparison that the decrease in the P-binding capacity with increasing soil P is less when P was added as turkey litter as compared to addition of P as fertilizer. The apparent binding affinity for P tended to increase when P was added as turkey litter but was unchanged with fertilizer P additions. One explanation is that the addition of the organic constituents from the turkey litter and/or their transformations in the soil led to the creation of additional organic P binding sites that are of lower affinity than those in the unamended soils. An alternative explanation is the changes in P sorption with turkey litter stem from increases in soil calcium (Ca). Sharpley et al. (2004) reported that long-term manure applications increased soil pH and soil levels of Ca and P. They postulated that the addition of Ca changes the soil's chemistry involving P from reactions with Al and Fe complexes to reactions with Ca complexes. Such a scenario may also explain differences in P-sorption kinetics reported here. Further research is needed to resolve which of these factors are responsible for the observed changes in P sorption.

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